



Solar Energy System Performance Evaluation

**ZIEN MECHANICAL CONTRACTORS No. 1
SINGLE-FAMILY RESIDENCE**

Milwaukee, Wisconsin

October 1978 Through March 1979



U.S. Department of Energy

**National Solar Heating and
Cooling Demonstration Program**

National Solar Data Program

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy \$5.25
Microfiche \$3.00

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

ZIEN MECHANICAL CONTRACTORS, NO. 1
MILWAUKEE, WISCONSIN

OCTOBER 1978 THROUGH MARCH 1979

CARL L. WERNER, PRINCIPAL AUTHOR
JONATHON M. NASH, MANAGER OF SOLAR ENERGY ANALYSIS
LARRY J. MURPHY, IBM PROGRAM MANAGER

IBM CORPORATION
18100 FREDERICK PIKE
GAITHERSBURG, MARYLAND 20760

PREPARED FOR
THE DEPARTMENT OF ENERGY
OFFICE OF ASSISTANT SECRETARY FOR
CONSERVATION AND SOLAR APPLICATION
UNDER CONTRACT EG-77-C-01-4049
H. JACKSON HALE, PROGRAM MANAGER

TABLE OF CONTENTS

	<u>Page</u>
1. FOREWORD	1-1
2. SUMMARY AND CONCLUSIONS.	2-1
2.1 Performance Summary	2-1
2.2 Conclusions	2-2
3. SYSTEM DESCRIPTION	3-1
4. PERFORMANCE EVALUATION TECHNIQUES	4-1
5. PERFORMANCE ASSESSMENT	5-1
5.1 Weather Conditions	5-2
5.2 System Thermal Performance	5-2
5.3 Subsystem Performance	5-9
5.3.1 Collector Array and Storage Subsystem.	5-9
5.3.1.1 Collector Array	5-9
5.3.1.2 Storage	5-13
5.3.2 Space Heating Subsystem	5-16
5.4 Operating Energy.	5-16
5.5 Energy Savings	5-19
6. REFERENCES	6-1
7. BIBLIOGRAPHY	7-1
APPENDIX A DEFINITIONS OF PERFORMANCE FACTORS AND SOLAR TERMS	A-1
APPENDIX B SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS	B-1
APPENDIX C LONG-TERM AVERAGE WEATHER CONDITIONS	C-1
APPENDIX D MONTHLY SOLAR ENERGY DISTRIBUTION FLOWCHARTS	D-1
APPENDIX E MONTHLY SOLAR ENERGY DISTRIBUTIONS	E-1

LIST OF ILLUSTRATIONS

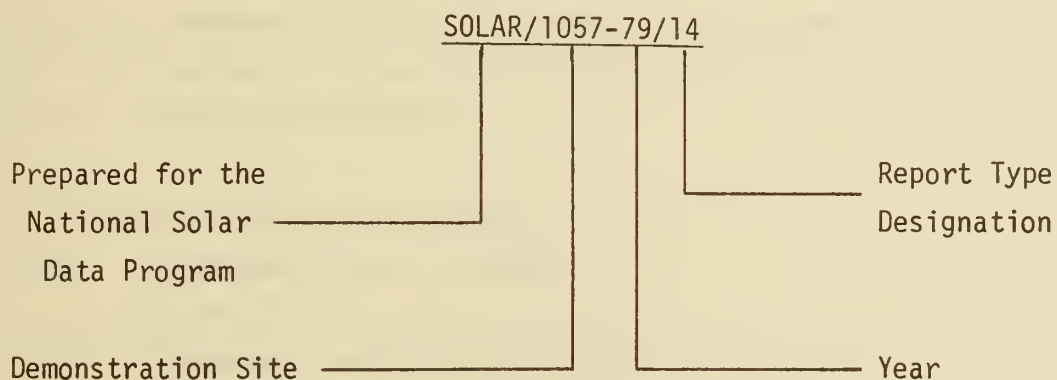
FIGURES	TITLE	PAGE
3-1	Solar Energy System Schematic	3-2
5-1	Solar Energy Distribution Flowchart Summary	5-6
D-1	Solar Energy Distribution Flowchart - October 1978	D-2
D-2	Solar Energy Distribution Flowchart - November 1978	D-3
D-3	Solar Energy Distribution Flowchart - December 1978	D-4
D-4	Solar Energy Distribution Flowchart - January 1979	D-5
D-5	Solar Energy Distribution Flowchart - February 1979	D-6
D-6	Solar Energy Distribution Flowchart - March 1979	D-7

LIST OF TABLES

TABLES	TITLE	PAGE
5-1	Weather Conditions	5-3
5-2	System Thermal Performance Summary	5-4
5-3	Solar Energy Distribution Summary	5-7
5-4	Solar Energy System Coefficient of Performance	5-8
5-5	Collector Array Performance	5-10
5-6	Storage Performance	5-14
5-7	Solar Energy Losses - Storage and Transport	5-15
5-8	Space Heating Subsystem Performance	5-17
5-9	Operating Energy	5-18
5-10	Energy Savings	5-20
E-1	Solar Energy Distribution - October 1978	E-2
E-2	Solar Energy Distribution - November 1978	E-3
E-3	Solar Energy Distribution - December 1978	E-4
E-4	Solar Energy Distribution - January 1979	E-5
E-5	Solar Energy Distribution - February 1979	E-6
E-6	Solar Energy Distribution - March 1979	E-7

NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under specific format. For example, this report for the Zien Mechanical Contractors No. 1 project site is designated as SOLAR/1057-79/14. The elements of this designation are explained in the following illustration.



o Demonstration Site Number:

Each project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

o Report Type Designation:

This number identifies the type of report, e.g.,

- Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December).
- Solar Energy System Performance Evaluations are designated by the number 14.

- Solar Project Descriptions are designated by the number 50.
- Solar Project Cost Reports are designated by the number 60.

These reports are disseminated through the U. S. Department of Energy Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

1. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy under the Solar Heating and Cooling Demonstration Act of 1974. The overall goal of this activity is to accelerate the establishment of a viable solar energy industry and to stimulate its growth to achieve a substantial reduction in nonrenewable energy resource consumption through widespread applications of solar heating and cooling technology.

Information gathered through the Demonstration Program is disseminated in a series of site-specific reports. These reports are issued as appropriate and may include such topics as:

- o Solar Project Description
- o Design/Construction Report
- o Project Costs
- o Maintenance and Reliability
- o Operational Experience
- o Monthly Performance
- o System Performance Evaluation

The International Business Machines (IBM) Corporation is contributing to the overall goal of the Demonstration Act by monitoring, analyzing, and reporting the thermal performance of solar energy systems through analysis of measurements obtained by the National Solar Data Program.

The Solar Energy System Performance Evaluation Report is a product of the National Solar Data Program. Reports are issued periodically to document the results of analysis of specific solar energy system operational performance. This report includes system description, operational characteristics and capabilities, and an evaluation of actual versus expected performance. The Monthly Performance Report, which is the basis for the Solar Energy System Performance Evaluation Report, is published on a regular basis. Each parameter presented in these reports as characteristic of system performance

represents over 8,000 discrete measurements obtained each month by the National Solar Data Network (NSDN). Documents referenced in this report are listed in Section 6, "References." Numbers shown in brackets refer to reference numbers in Section 6. All other documents issued by the National Solar Data Program for the Zien Mechanical Contractors No. 1 solar energy system are listed in Section 7, "Bibliography."

This Solar Energy System Performance Evaluation Report presents the results of a thermal performance analysis of the Zien Mechanical Contractors No. 1 solar energy system. The analysis covers operation of the system from October 1978 through March 1979. Zien Mechanical Contractors No. 1 solar energy system provides space heating and space cooling to a single-family residence located in Milwaukee, Wisconsin. Section 2 presents a summary of the overall system results. A system description is contained in Section 3. Analysis of the system thermal performance was accomplished using a system energy balance technique described in Section 4. Section 5 presents a detailed assessment of the individual subsystems applicable to the site.

The measurement data for the reporting period were collected by the NSDN [1]. System performance data are provided through the NSDN via an IBM-developed Central Data Processing System (CDPS) [2]. The CDPS supports the collection and analysis of solar data acquired from instrumented systems located throughout the country. This data is processed daily and summarized into monthly performance reports. These monthly reports form a common basis for system evaluation and are the source of the performance data used in this report.

Acknowledgment is extended to Mr. Larry A. Weidinger, who is involved in the operation of the Zien Mechanical Contractors' solar energy system. His cooperation in the resolution of various on-site problems during the reporting period was invaluable.

2. SUMMARY AND CONCLUSIONS

This section provides a summary of the performance of the solar energy system installed at Zien Mechanical Contractors No. 1, located in Milwaukee, Wisconsin for the period October 1978 through March 1979. This solar energy system is designed to support the space heating and space cooling loads. A detailed description of the Zien Mechanical Contractors No. 1 solar energy system operation is presented in Section 3.

2.1 Performance Summary

The solar energy site was unoccupied from October 1978 through March 1979 and the solar energy system operated continuously during this reporting period. The total incident solar energy was 55.47⁽¹⁾ million Btu. Solar energy satisfied 63 percent of the space heating requirements. The solar energy system provided an electrical savings of 19.14⁽²⁾ million Btu.

During October the weather was mild and the incident solar energy was somewhat below the expected value. The weather turned colder during the rest of the reporting period and was sharply below the expected values for January and February 1979. The incident solar energy fell as well and was markedly below expectation for February. The cold weather produced an increase in the average number of heating degree days for the months measured at 1378 versus an expected value of 1034.

The collector subsystem operated continuously during the period at an average operational efficiency of 45 percent. The collector maintained an average storage temperature of 58°F throughout the period and never permitted the rock storage bin to fall below 36°F. The latter value was measured during

(1) Summation based on 5-month data: October, November, December (1978), February, March (1979).

(2) Summation based on 6-month data: October 1978 through March 1979.

January when the average outside temperature for the month was 10°F. Instrument difficulties resulting from accumulated snow and unusually low temperatures prevented the measurement of the total energy collected and delivered to the storage bin. The solar energy system provided a total of 29.42 million Btu toward the satisfaction of a space heating load of 47.07 million Btu. The solar energy was collected using operational energy of 3.51 million Btu.

Large energy losses occur in the collector/storage loop of the Zien Mechanical Contractors No. 1 system. The losses are attributed primarily to air leakage from the collector array and, to a lesser extent, from the storage room. The losses are proportionately greater when there is little demand as in October 1978. Under such circumstances, the losses may exceed 90 percent of the collected energy since the system maintains storage at a high temperature with little of the energy used for heating. The percentage of loss declines as more solar energy is used, but it still remains undesirably high and averaged approximately 50 percent throughout the heating season.

Solar energy supplied between 49 percent and 65 percent of the monthly energy used for heating during the reporting period. The resulting electrical savings were 19.12 million Btu for the system during the reporting period.

2.2 Conclusions

The Zien Mechanical Contractors No. 1 site provided significant energy savings in spite of leakage in the collector array. The solar energy system provided an average of 63 percent of the heating requirements for the Zien Mechanical Contractors No. 1 site during the reporting period. It is expected that the Zien Mechanical Contractors No. 1 site would experience improved system performance if the leakage in the collector subsystem was reduced. Improvement by reduction of the 35 to 50 percent losses will increase the efficiency of the solar energy system and enhance the operation of the solar-assisted heat pump.

3. SYSTEM DESCRIPTION

Zien Mechanical Contractors No. 1 is a single-family residence in Milwaukee, Wisconsin. The home has approximately 1304 square feet of conditioned space. The solar energy system consists of two independently controlled systems: one system serves domestic hot water (DHW) preheating; the other is used for space heating and space cooling. Only the space heating and cooling system is described in this report.

The system has an array of flat-plate collectors with a gross area of 384 square feet. The array faces south at an angle of 53 degrees to the horizontal. Air is the transfer medium that delivers solar energy from the collector array to storage. Solar energy is stored in a rock bin containing 41,250 pounds of rock located in the basement of the house. The rock bin has 2 inches of polyurethane insulation on the outside walls and fiberglass roll insulation in the ceiling. A heat pump delivers solar energy from storage to a heat exchanger located within an air-handler. Heated air is then blown from the air-handler to the load. When solar energy is insufficient to satisfy the space heating load, an electric resistance heater in the air-handler provides auxiliary energy for space heating. The system, shown schematically in Figure 3-1, has 10 modes of solar operation for space conditioning.

Mode 1 - Storage-to-Heat Pump-to-Space Heating: This winter mode activates when there is a demand for space heating, the collector loop is not active, and the outside ambient temperature is less than 10°F above the rock bed temperature. Air is drawn through motorized dampers from storage by the collector/heat pump circulating fan, goes past the heat pump evaporator coil, bypasses the collector, and returns to storage. The heat pump condenser coil and house circulating fan supply energy to the house, and electrical strip heaters supplement the heat pump to meet the heating demand.

Mode 2 - Collector-to-Storage: This winter mode activates when the temperature difference between the collector outlet and storage is 10°F or higher, and the outside ambient temperature is less than 10°F above the rock bed

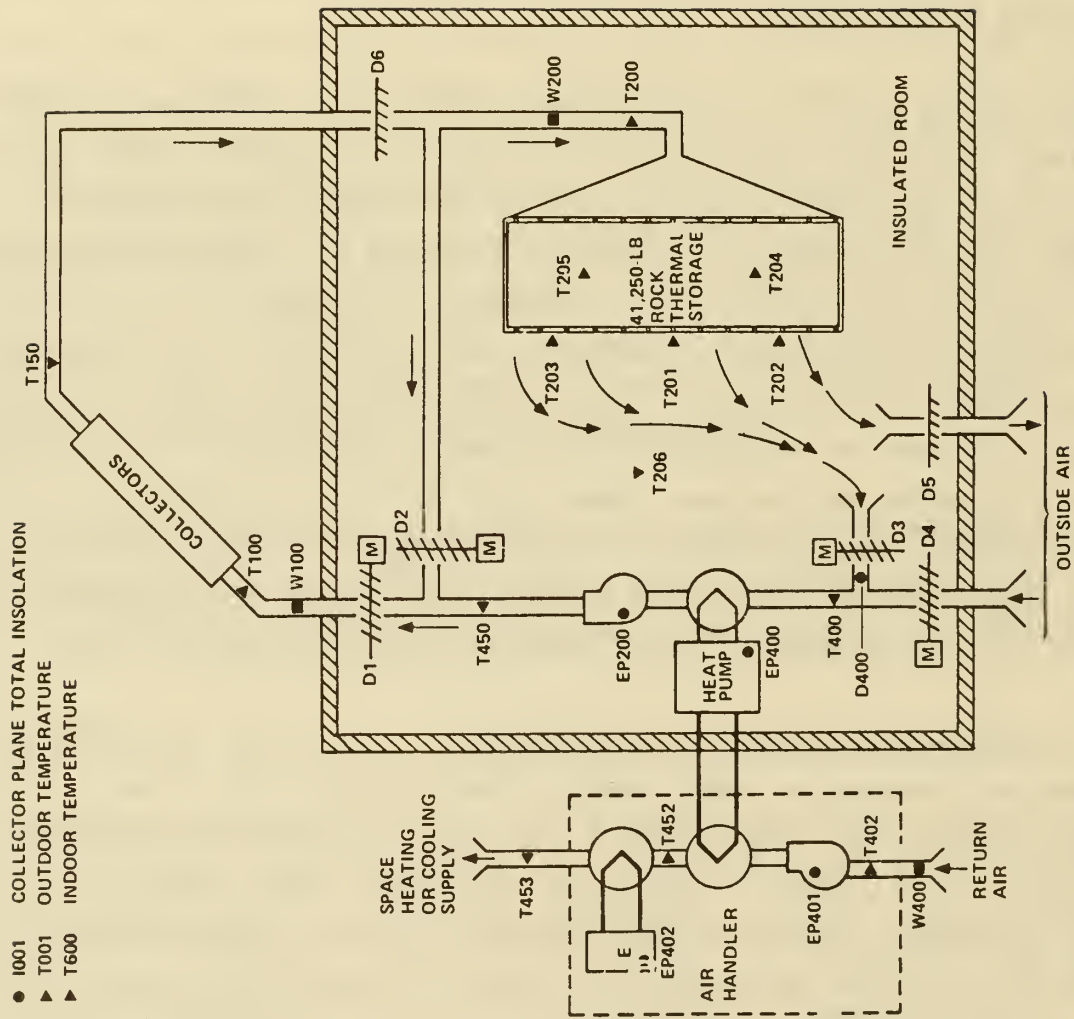


FIGURE 3-1. SOLAR ENERGY SYSTEM SCHEMATIC
ZIEN MECHANICAL CONTRACTORS NO. 1

temperature. Air is drawn from the collector by the collector/heat pump circulating fan, goes into the rock bin through motorized dampers, and then recirculates through the collector. There may or may not be a demand for space heating.

Mode 3 - Outside Air-to-Rock Bed: This mode activates when the collector loop is inactive, there is no demand for space heating, and the outside ambient temperature is higher than 10°F above the rock-bed temperature. Air is drawn from the outside by the collector/heat pump circulating fan, goes into the rock bin through motorized dampers, and then exhausts to the outside through a backdraft damper in the wall of the insulated room.

Mode 4 - Outside Air-to-Heat Pump-to-Space Heating: This winter mode activates when there is a demand for space heating, the collector loop is not active, and the outside ambient temperature is more than 10°F above the rock bed temperature. Air is drawn from the outside through motorized dampers, passes the heat pump evaporator coil, goes through the storage bin, and then exhausts to the outside through a backdraft damper in the wall of the insulated room. The heat pump condenser coil and house circulating fan supply energy to the house. Electric strip heaters supplement the heat pump to meet the heating demand.

Mode 5 - Outside Air-to-Collector-to-Rock Bed: This mode activates when the difference in temperature between the collector outlet and storage is 10°F or higher, and the outside ambient temperature is more than 10°F above the rock bed temperature. Air is drawn from the outside by the collector/heat pump circulating fan, goes through the collector and into the rock bin through motorized dampers, and then exhausts to the outside. There may or may not be a demand for space heating.

Mode 6 - Storage-to-Heat Pump-to-Space Cooling: This summer mode activates when there is a demand for space cooling, the collector loop is not active, and the rock bed temperature is less than 10°F above the outside ambient temperature. Air is drawn through motorized dampers from storage by the

collector/heat pump fan, goes past the heat pump condenser coil, bypasses the collector, and returns to storage. The heat pump evaporator coil and house circulating fan remove energy from the house.

Mode 7 - Collector-to-Storage for Cooling: This mode rejects rock bed energy by circulating air through the collector at night. This summer mode activates when the temperature difference between the rock bed and the collector outlet is 10°F or higher, and the rock bed temperature is less than 10°F above the outside ambient temperature. Air is drawn from the collector at night by the collector/heat pump circulating fan, goes into the rock bin through motorized dampers, and then recirculates through the collector. There may or may not be a demand for space cooling.

Mode 8 - Outside Air-to-Rock Bed for Cooling: This mode activates when the collector loop is inactive, there is no demand for space cooling, and the rock bed temperature is more than 10°F above the outside ambient temperature. Air is drawn from the outside by the collector/heat pump circulating fan, goes into the rock bin through motorized dampers, and then exhausts to the outside through a backdraft damper in the wall of the insulated room.

Mode 9 - Outside Air-to-Heat Pump-to-Space Cooling: This summer mode activates when there is a demand for space cooling, the collector loop is not active, and the rock bed temperature is more than 10°F above the outside ambient temperature. Air is drawn from the outside through motorized dampers to the heat pump, passes the heat pump condenser coil, goes through the storage bin, and then exhausts to the outside through a backdraft damper in the wall of the insulated room. The heat pump evaporator coil and house circulating fan remove energy from the house to meet the cooling load.

Mode 10 - Outside Air-to-Collector-to-Rock Bed: This mode activates when the temperature difference between the rock bed and collector outlet is 10°F or higher, and the rock bed temperature is higher than 10°F above the outside ambient temperature. Air is drawn from the outside by the collector/heat pump circulating fan, goes into the rock bin through motorized dampers, and then exhausts to the outside. There may or may not be a demand for space cooling.

4. PERFORMANCE EVALUATION TECHNIQUES

The performance of the Zien Mechanical Contractors No. 1 solar energy system is evaluated by calculating a set of primary performance factors which are based on those proposed in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" [3]. These performance factors quantify the thermal performance of the system by measuring the amount of energies that are being transferred between the components of the system. The performance of the system can then be evaluated based on the efficiency of the system in transferring these energies. All performance factors and their definitions are listed in Appendix A.

Data from monitoring instrumentation located at key points within the solar energy system are collected by the National Solar Data Network. This data is first formed into factors showing the hourly performance of each system component, either by summation or averaging techniques, as appropriate. The hourly factors then serve as a basis for calculating the daily and monthly performance of each component subsystem. The performance factor equations for this site are listed in Appendix B.

Each month, as appropriate, a summary of overall performance of the Zien Mechanical Contractors No. 1 site and a detailed subsystem analysis are published. These monthly reports for the period covered by this Solar Energy System Performance Evaluation (October 1978 through March 1979) are available from the Technical Information Center, Oak Ridge, Tennessee 37830.

In addition, data are included in this report for which monthly reports are not available. This data is included with the intention of making this report as comprehensive as possible. Months for which no published monthly reports exist are shown in parentheses in the tables and figures. In the tables and figures in this report, an asterisk indicates that the value is not available for that month; N.A. indicates that the value is not applicable for this site.

5. PERFORMANCE ASSESSMENT

The performance of the Zien Mechanical Contractors No. 1 solar energy system has been evaluated for the October 1978 through March 1979 time period. Two perspectives were taken in this assessment. The first views the overall system in which the total solar energy collected, the system load, the measured values for solar energy used, and system solar fraction are presented. Where applicable, the expected values for solar energy used and system solar fraction are also shown. The expected values have been derived from a modified f-chart analysis which uses measured weather and subsystem loads as input. The f-chart is a performance estimation technique used for designing solar heating systems. It was developed by the Solar Energy Laboratory, University of Wisconsin - Madison. The system mode used in the analysis is based on manufacturer's data and other known system parameters. In addition, the solar energy system coefficient of performance (COP) at both the system and subsystem level has been presented.

The second view presents a more in-depth look at the performance of individual subsystems. Details relating to the performance of the collector array and storage subsystems are presented first, followed by details pertaining to the space heating and domestic hot water (DHW) subsystems. Included in this section are all parameters pertinent to the operation of each individual subsystem.

In addition to the overall system and subsystem analysis, this report also describes the equivalent energy savings contributed by the solar energy system. The overall system and individual subsystem energy savings are presented in Section 5.5.

The performance assessment of any solar energy system is highly dependent on the prevailing weather conditions at the site during the period of performance. The original design of the system is generally based on the long-term averages for available insolation and temperature. Deviations from these long-term averages can significantly affect the performance of the system. Therefore,

before beginning the discussion of actual system performance, a presentation of the measured and long-term averages for critical weather parameters has been provided.

5.1 Weather Conditions

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the Zien Mechanical Contractors No. 1 site during the reporting period are presented in Table 5-1. Also presented in Table 5-1 are the corresponding long-term average monthly values of the measured weather parameters. These data are taken from Reference Monthly Environmental Data for Systems in the National Solar Data Network [4]. A complete yearly listing of these values for the site is given in Appendix C.

During October 1978 through March 1979 the average daily total incident solar energy on the collector array was 954 Btu per square foot per day. This was below the estimated average daily solar radiation for this geographical area during the reporting period of 1065 Btu per square foot per day for a south-facing plane with a tilt of 53 degrees to the horizontal. The average ambient temperature during October 1978 through March 1979 was 28°F as compared with the long-term average for October through March of 31°F.

5.2 System Thermal Performance

The thermal performance of a solar energy system is a function of the total solar energy collected and applied to the system load. The total system load is the sum of the useful energy delivered to the loads (excluding losses in the system), both solar and auxiliary thermal energies. The portion of the total load provided by solar energy is defined as the solar fraction of the load.

The thermal performance of the Zien Mechanical Contractors No. 1 solar energy system is presented in Table 5-2. This performance assessment is based on

TABLE 5-1. WEATHER CONDITIONS
ZIEN MECHANICAL CONTRACTORS NO. 1

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA ⁽¹⁾ (Btu/Ft ²)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
OCT	1190	1338	50	51	*	440	*	0
NOV	846	927	37	37	*	855	*	0
(DEC)	787	726	22	24	*	1265	*	0
(JAN)	*	904	10	19	1706	1414	*	0
(FEB)	863	1148	15	23	1405	1190	*	0
(MAR)	1084	1346	32	31	1023	1042		0
TOTAL					4134 ⁽³⁾	6206	*	0
AVERAGE	954 ⁽²⁾	1065	28	31	1378 ⁽³⁾	1034	*	0

(1) - In collector array plane and azimuth, unless otherwise indicated in Section 5.1.

(2) - Average based on 5-month data: October, November, December 1978; February, March 1979.

(3) - Summation and average based on 3-month data: January, February, March 1979.

* - Denotes unavailable data

S002

TABLE 5-2. SYSTEM THERMAL PERFORMANCE SUMMARY
ZIEN MECHANICAL CONTRACTORS NO. 1

MONTH	SOLAR ENERGY COLLECTED (Million Btu)	SYSTEM LOAD (Million Btu)	SOLAR ENERGY USED (Million Btu)		SOLAR FRACTION (%)	
			EXPECTED	MEASURED	EXPECTED	MEASURED
OCT	6.08	0.48	*	0.23	*	49
NOV	4.30	2.65	*	1.38	*	52
(DEC)	*	10.67	*	6.98	*	65
(JAN)	*	14.69	*	8.75	*	60
(FEB)	*	11.53	*	7.47	*	65
(MAR)	*	7.05	*	4.61	*	65
TOTAL	10.38 ⁽¹⁾	47.07	*	29.42		
AVERAGE	5.19 ⁽¹⁾	7.85	*	4.90	*	63

S002

* - Denotes unavailable data

(1) - Summation and average based on 2-month data: October 1978 and November 1978

the 6-month period from October 1978 to March 1979. During the reporting period, the total system load was 47.07 million Btu, and the measured amount of solar energy delivered to the load subsystem was 29.42 million Btu. The measured system solar fraction was 63 percent.

Figure 5-1 illustrates the flow of solar energy from the point of collection to the various points of consumption and loss for the reporting period. The numerical values account for the quantity of energy corresponding with the transport, operation, and function of each major element in the Zien Mechanical Contractors No. 1 solar energy system for the total reporting period.

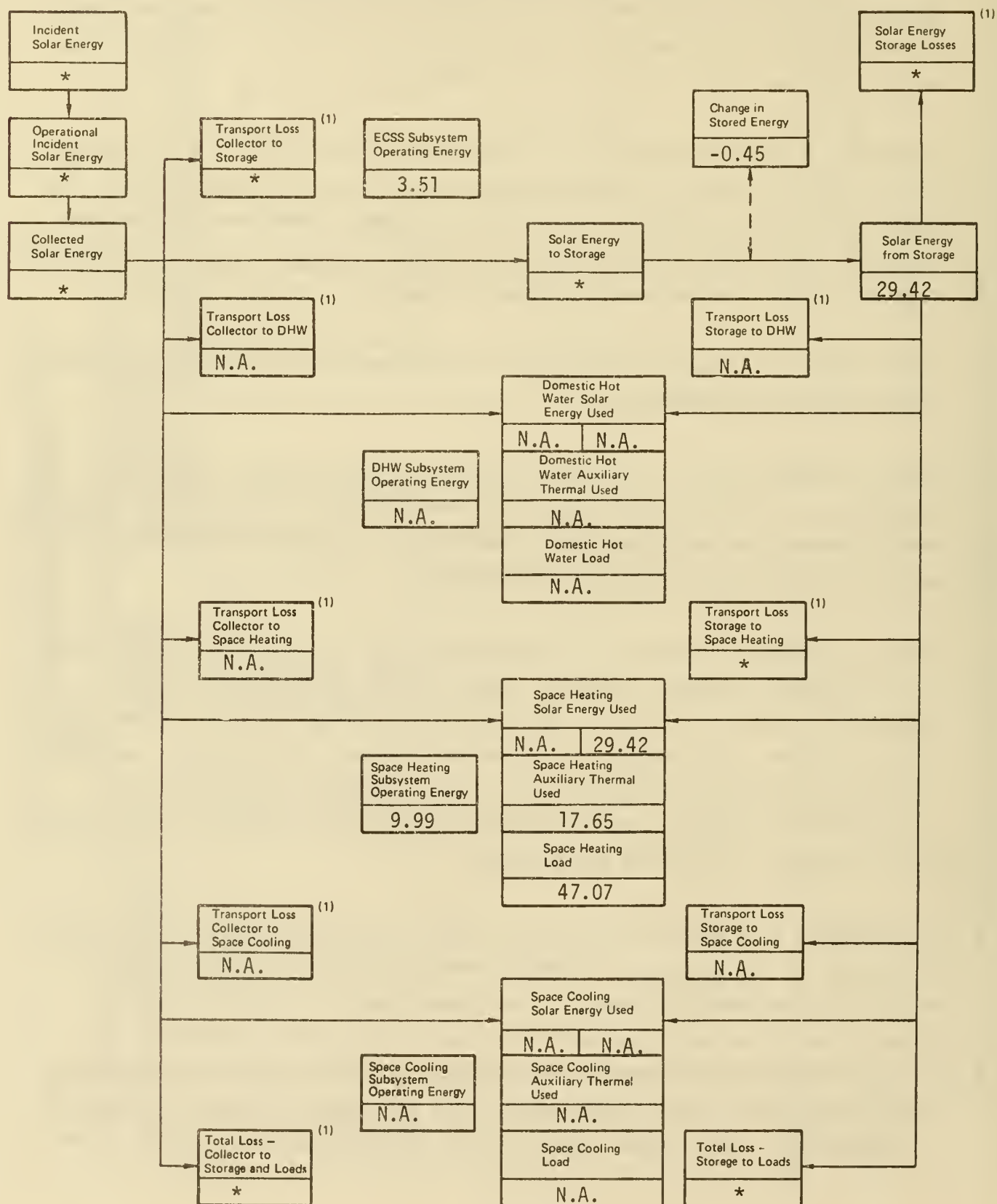
Solar energy distribution flowcharts for each month of the reporting period are presented in Appendix D.

Table 5-3 summarizes solar energy distribution and provides a percentage breakdown. For the period October 1978 through March 1979, the load subsystems energy consumption and losses were undetermined. Appendix E contains the monthly solar energy percentage distributions.

The solar energy coefficient of performance (COP) is indicated in Table 5-4. The COP simply provides a numerical value for the relationship of solar energy collected or transported or used and the energy required to perform the transition. The greater the COP value, the more efficient the subsystem. The COP for the solar energy system at Zien Mechanical Contractors No. 1 functioned at a reporting period weighted average COP value of 2.79 for the period October 1978 through March 1979.

The presence of a solar-assisted heat pump in the system design, necessitates allocation of the compressor operating energy to auxiliary heating and to heating system operating energy. The apportionment is arbitrary and is based primarily on empirical data from general heat pump operation. In the case of the Zien Mechanical Contractors No. 1 site, the heat pump operating energy effects were approximated using the solar fraction calculated in the normal way. This value, the value for solar energy used, and the value

FIGURE 5-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART SUMMARY
ZIEN MECHANICAL CONTRACTORS NO. 1



* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known - see text for discussion)

S002

TABLE 5-3. SOLAR ENERGY DISTRIBUTION SUMMARY - OCTOBER 1978 TO MARCH 1979
ZIEN MECHANICAL CONTRACTORS NO. 1

$\frac{*}{100\%}$ million Btu TOTAL SOLAR ENERGY COLLECTED

$\frac{29.42}{* \%}$ million Btu SOLAR ENERGY TO LOADS

$\frac{N.A.}{\%}$ million Btu SOLAR ENERGY TO DHW SUBSYSTEM

$\frac{29.42}{* \%}$ million Btu SOLAR ENERGY TO SPACE HEATING SUBSYSTEM

$\frac{N.A.}{\%}$ million Btu SOLAR ENERGY TO SPACE COOLING SUBSYSTEM

$\frac{*}{* \%}$ million Btu SOLAR ENERGY LOSSES

$\frac{*}{* \%}$ million Btu SOLAR ENERGY LOSS FROM STORAGE

$\frac{*}{* \%}$ million Btu SOLAR ENERGY LOSS IN TRANSPORT

$\frac{*}{* \%}$ million Btu COLLECTOR TO STORAGE LOSS

$\frac{N.A.}{\%}$ million Btu COLLECTOR TO LOAD LOSS

$\frac{N.A.}{\%}$ million Btu COLLECTOR TO DHW LOSS

$\frac{*}{* \%}$ million Btu COLLECTOR TO SPACE HEATING LOSS

$\frac{N.A.}{\%}$ million Btu COLLECTOR TO SPACE COOLING LOSS

$\frac{*}{* \%}$ million Btu STORAGE TO LOAD LOSS

$\frac{N.A.}{\%}$ million Btu STORAGE TO DHW LOSS

$\frac{*}{* \%}$ million Btu STORAGE TO SPACE HEATING LOSS

$\frac{N.A.}{\%}$ million Btu STORAGE TO SPACE COOLING LOSS

$\frac{-0.45}{* \%}$ million Btu SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data

N.A. - Denotes not applicable data

TABLE 5-4. SOLAR ENERGY SYSTEM COEFFICIENT OF PERFORMANCE
ZIEN MECHANICAL CONTRACTORS NO. 1

MONTH	SOLAR ENERGY SYSTEM COP	COLLECTOR ARRAY SUBSYSTEM SOLAR COP	DOMESTIC HOT WATER SUBSYSTEM SOLAR COP	SPACE HEATING SUBSYSTEM SOLAR COP	SPACE COOLING SUBSYSTEM SOLAR COP
OCT	0.63	20.97	N.A.	3.13	N.A.
NOV	1.79	11.94	N.A.	3.36	N.A.
(DEC)	3.13	*	N.A.	4.63	N.A.
(JAN)	3.46	*	N.A.	5.17	N.A.
(FEB)	3.27	*	N.A.	4.81	N.A.
(MAR)	2.96	*	N.A.	4.67	N.A.
WEIGHTED AVERAGE	3.02	*	N.A.	4.72	N.A.

S002

* - Denotes unavailable data

N.A. - Denotes not applicable data

for operating energy for both collector and space heating loops were valid throughout the reporting period and were not influenced by instrument problems.

Using the values described, the resulting calculations indicate that an average system COP of 3.02 was achieved.

The system therefore supplied nearly three times as much solar energy to space heating as was required to make the solar energy available for use.

Additionally, the space heating subsystem provided an even better result. The COP for this subsystem was estimated to be 4.72, indicating somewhat better performance than the system as a whole.

5.3 Subsystem Performance

The Zien Mechanical Contractors No. 1 solar energy installation may be divided into 2 subsystems:

1. Collector Array and Storage
2. Space Heating

Each subsystem is evaluated and analyzed by the techniques defined in Section 4 to produce the monthly performance reports. This section presents the results of integrating the monthly data available on the 2 subsystems for the period October 1978 through March 1979.

5.3.1 Collector Array and Storage Subsystem

5.3.1.1 Collector Array

Collector array performance for the Zien Mechanical Contractors No. 1 site is presented in Table 5-5. The total incident solar radiation on the collector

TABLE 5-5. COLLECTOR ARRAY PERFORMANCE
ZIEN MECHANICAL CONTRACTORS NO. 1

MONTH	INCIDENT SOLAR ENERGY (Million Btu)	COLLECTED SOLAR ENERGY (Million Btu)	COLLECTOR ARRAY EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY (Million Btu)	OPERATIONAL COLLECTOR ARRAY EFFICIENCY (%)
OCT	14.17	6.08	43	13.70	44
NOV	9.75	4.30	44	9.31	46
(DEC)	9.37	*	*	8.68	*
(JAN)	*	*	*	*	*
(FEB)	9.28	*	*	8.70	*
(MAR)	12.90	*	*	12.16	*
TOTAL	55.47 ⁽¹⁾	10.38 ⁽²⁾		52.55	
AVERAGE	11.09 ⁽¹⁾	5.19 ⁽²⁾	43 ⁽²⁾	10.51 ⁽¹⁾	45 ⁽²⁾

(1) - Summation and average based on 5-month data: October, November, December 1978; February, March 1979

(2) - Summation and average based on 2-month data: October, November 1978

* - Denotes unavailable data

S002

array for the period October 1978 through March 1979 was 55.47⁽¹⁾ million Btu. During the period the collector loop was operating the total insolation amounted to 52.55⁽¹⁾ million Btu. The total collected solar energy for the period October and November 1978 was 10.38 million Btu, resulting in a collector array efficiency of 43 percent, based on total incident insolation. Solar energy delivered from the collector array to storage was 10.38 million Btu during October and November 1978. Energy loss during transfer from the collector array to storage and loads was undetermined. Operating energy required by the collector loop for the total reporting period was 3.51 million Btu.

Instrument problems prevented the determination of collected solar energy for December 1978, January, February, and March 1979. For this reason, losses and efficiencies based on this measurement were also not determined. October and November of 1978 values are, however, presented in the tables.

Collector array efficiency has been computed from two bases. The first assumes the that efficiency is based upon all available solar energy. This approach makes the operation of the control system part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; therefore, the energy is not collected. In this approach, collector array performance is described by comparing the collected solar energy to the incident solar energy. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$\eta_c = Q_s / Q_i$$

where: η_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

⁽¹⁾ Summation based on 5-month data: October, November, December (1978), February, March (1979).

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Efficiency" in Table 5-5.

The second approach assumes the efficiency is based upon the incident solar energy during the periods of collection only.

Evaluating collector efficiency using operational incident energy and compensating for the difference between gross collector array area and the gross collector area yield operational collector efficiency. Operational collector efficiency, η_{co} , is computed as follows:

$$\eta_{co} = Q_s / (Q_{oi} \times \frac{A_p}{A_a})$$

where: Q_s = collected solar energy

Q_{oi} = operational incident energy

A_p = gross collector area (product of the number of collectors and the total envelope area of one unit)

A_a = gross collector array area (total area perpendicular to the solar flux vector, including all mounting, connecting and transport hardware)

Note: The ratio $\frac{A_p}{A_a}$ is typically 1.0 for most collector array configurations.

The monthly efficiency computed by this method is listed in the column entitled "Operational Collector Array Efficiency" in Table 5-5. This latter efficiency term is not the same as collector efficiency as represented by the ASHRAE Standard 93-77 [5]. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector, and both use the same definition

of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 5-5.

5.3.1.2 Storage

Storage performance data for the Zien Mechanical Contractors No. 1 site for the reporting period is shown in Table 5-6. Results of analysis of solar energy losses during transport and storage are shown in Table 5-7. This table contains an evaluation of solar energy transport losses as a fraction of energy transported to subsystems.

During the reporting period, there were 29.42 million Btu delivered from storage to the space heating subsystem. Energy loss from storage was undetermined. The average storage temperature for the period was 58°F.

Storage subsystem performance is evaluated by comparison of energy to storage, energy from storage, and the change in stored energy. The ratio of the sum of energy from storage and the change in stored energy, to the energy to storage is defined as storage efficiency, η_s . This relationship is expressed in the equation

$$\eta_s = (\Delta Q + Q_{so})/Q_{si}$$

where:

ΔQ = change in stored energy. This is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value)

TABLE 5-6. STORAGE PERFORMANCE
ZIEN MECHANICAL CONTRACTORS NO. 1

MONTH	ENERGY TO STORAGE (Million Btu)	ENERGY FROM STORAGE (Million Btu)	CHANGE IN STORED ENERGY (Million Btu)	STORAGE EFFICIENCY (%)	STORAGE AVERAGE TEMPERATURE (°F)	EFFECTIVE STORAGE HEAT LOSS COEFFICIENT (Btu/Hr -- °F)
OCT	6.08	0.23	0.04	5	92	N.A.
NOV	4.30	1.38	-0.43	22	72	N.A.
(DEC)	*	6.98	-0.20	*	43	N.A.
(JAN)	*	8.75	0.12	*	36	N.A.
(FEB)	*	7.47	0.05	*	47	N.A.
(MAR)	*	4.61	-0.03	*	57	N.A.
TOTAL	10.38 ⁽¹⁾	29.42	-0.45			
AVERAGE	5.19 ⁽¹⁾	4.90	-0.08	12 ⁽¹⁾	58	N.A.

(1) - Summation and average based on 2-month data: October and November 1978.

* - Denotes unavailable data

N.A. - Denotes not applicable data

S002

TABLE 5-7. SOLAR ENERGY LOSSES - STORAGE AND TRANSPORT
ZIEN MECHANICAL CONTRACTORS NO. 1

	MONTH							TOTAL
	OCT	NOV	DEC	JAN	FEB	MAR		
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million Btu)	6.08	4.30	*	*	*	*		*
2. SE TO STORAGE (million Btu)	6.08	4.30	*	*	*	*		*
3. LOSS - COLLECTOR TO STORAGE (%) $\frac{1-2}{1}$	0	0	*	*	*	*		*
4. CHANGE IN STORED ENERGY (million Btu)	0.04	-0.43	-0.20	0.12	0.05	-0.03		-0.45
5. SOLAR ENERGY - STORAGE TO DHW SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		N.A.
6. SOLAR ENERGY - STORAGE TO SPACE HEATING SUBSYSTEM (million Btu)	0.23	1.38	6.98	8.75	7.47	4.61		29.42
7. SOLAR ENERGY - STORAGE TO SPACE COOLING SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		N.A.
8. LOSS FROM STORAGE (%) $\frac{2-(4+5+6+7)}{2}$	96	78	*	*	*	*		*
9. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		N.A.
10. LOSS - STORAGE TO HWSE (%) $\frac{5-9}{5}$	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		N.A.
11. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million Btu)	0.23	1.38	6.98	8.75	7.47	4.61		29.42
12. LOSS - STORAGE TO HSE (%) $\frac{6-11}{6}$	0	0	0	0	0	0		

S002

N.A. - Denotes not applicable data

* - Denotes unavailable data

Q_{so} = energy from storage. This is the amount of energy extracted by the load subsystem from the primary storage medium

Q_{si} = energy to storage. This is the amount of energy (both solar and auxiliary) delivered to the primary storage medium

5.3.2 Space Heating Subsystem

The space heating subsystem performance for the Zien Mechanical Contractors No. 1 site for the reporting period is shown in Table 5-8. The space heating subsystem consumed 29.42 million Btu of solar energy and 17.65 million Btu of auxiliary electrical energy to satisfy a space heating load of 47.07 million Btu. The solar fraction of this load was 63 percent.

The performance of the space heating subsystem is described by comparing the amount of solar energy supplied to the subsystem with the energy required to satisfy the total space heating load. The energy required to satisfy the total load consists of both solar energy and auxiliary thermal energy. The ratio of solar energy supplied to the load to the total load is defined as the heating solar fraction.

5.4 Operating Energy

Measured values of the Zien Mechanical Contractors No. 1 solar energy system and subsystem operating energy for the reporting period are presented in Table 5-9. A total of 13.50 million Btu of operating energy was consumed by the entire system during the reporting period.

Operating energy for a solar energy system is defined as the amount of electrical energy required to support the subsystems without affecting their thermal state.

TABLE 5-8. SPACE HEATING SUBSYSTEM PERFORMANCE
ZIEN MECHANICAL CONTRACTORS NO. 1

MONTH	SPACE HEATING LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
OCT	0.48	0.23	0.25	0.25	N.A.	49
NOV	2.65	1.38	1.27	1.27	N.A.	52
(DEC)	10.67	6.98	3.70	3.70	N.A.	65
(JAN)	14.69	8.75	5.93	5.93	N.A.	60
(FEB)	11.53	7.47	4.06	4.06	N.A.	65
(MAR)	7.05	4.61	2.44	2.44	N.A.	65
TOTAL	47.07	29.42	17.65	17.65	N.A.	
AVERAGE	7.85	4.90	2.94	2.94	N.A.	63

N.A. - Denotes not applicable data

S002

TABLE 5-9. OPERATING ENERGY
ZIEN MECHANICAL CONTRACTORS NO. 1

MONTH	ENERGY COLLECTION AND STORAGE OPERATING ENERGY (Million Btu)	DOMESTIC HOT WATER OPERATING ENERGY (Million Btu)	SPACE HEATING OPERATING ENERGY (Million Btu)	SPACE COOLING OPERATING ENERGY (Million Btu)	TOTAL SYSTEM OPERATING ENERGY (Million Btu)
OCT	0.29	N.A.	0.15	N.A.	0.44
NOV	0.36	N.A.	0.79	N.A.	1.15
(DEC)	0.72	N.A.	2.32	N.A.	3.04
(JAN)	0.84	N.A.	2.82	N.A.	3.66
(FEB)	0.73	N.A.	2.39	N.A.	3.12
(MAR)	0.57	N.A.	1.52	N.A.	2.09.
TOTAL	3.51	N.A.	9.99	N.A.	13.50
AVERAGE	0.59	N.A.	1.67	N.A.	2.25

N.A. - Denotes not applicable data

S002

Total system operating energy for Zien Mechanical Contractors No. 1 is the energy required to support the energy collection and storage subsystem (ECSS), and the space heating subsystem. With reference to the system schematic (Figure 3-1), the ECCS operating energy includes the collector pump EP200. The space heating subsystem operating energy consists of the heat pump power EP400, and the air-handler blower EP401.

5.5 Energy Savings

Energy savings for the Zien Mechanical Contractors No. 1 site for the reporting period are presented in Table 5-10. For this period the total savings on electrical energy were 19.12 million Btu, for a monthly average of 3.19 million Btu. An electrical energy expense of 3.51 million Btu was incurred during the reporting period for the operation of solar energy transportation pumps.

Solar energy system savings are realized whenever energy provided by the solar energy system is used to meet system demands which would otherwise be met by auxiliary energy sources. The operating energy required to provide solar energy to the load subsystems is subtracted from the solar energy contribution to determine net savings.

The auxiliary source at Zien Mechanical Contractors No. 1 consists of electrical resistance heaters. The units are considered to be 100 percent efficient for computational purposes.

TABLE 5-10. ENERGY SAVINGS
ZIEN MECHANICAL CONTRACTORS NO. 1

MONTH	SOLAR ENERGY USED (Million Btu)	SOLAR ENERGY SAVINGS ATTRIBUTED TO (Million Btu)						SOLAR OPER- ATING ENERGY (Million Btu)	ENERGY SAVINGS (Million Btu)	
		SPACE HEATING		DOMESTIC HOT WATER		SPACE COOLING			ELEC- TRICAL	FOSSIL FUEL
		ELEC- TRICAL	FOSSIL FUEL	ELEC- TRICAL	FOSSIL FUEL	ELEC- TRICAL	FOSSIL FUEL			
OCT	0.23	0.13	N.A.	N.A.	N.A.	N.A.	0.36	0.16	N.A.	
NOV	1.38	0.84	N.A.	N.A.	N.A.	N.A.	0.77	0.48	N.A.	
(DEC)	6.98	5.41	N.A.	N.A.	N.A.	N.A.	2.23	4.69	N.A.	
(JAN)	8.75	6.85	N.A.	N.A.	N.A.	N.A.	2.53	6.01	N.A.	
(FEB)	7.47	5.83	N.A.	N.A.	N.A.	N.A.	2.28	5.10	N.A.	
(MAR)	4.61	3.57	N.A.	N.A.	N.A.	N.A.	1.55	3.00	N.A.	
TOTAL	29.42	22.63	N.A.	N.A.	N.A.	N.A.	9.72	19.12	N.A.	
AVERAGE	4.90	3.77	N.A.	N.A.	N.A.	N.A.	1.62	3.19	N.A.	

N.A. - Denotes not applicable data

S002

6. REFERENCES

1. U.S. Department of Energy, National Solar Data Network, prepared under contract number EG-77-C-4049 by IBM Corporation, December 1977.
2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.
3. E. Streed, et. al., Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.
4. Mears, J. C. Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.
5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.
- 6.# Monthly Performance Report, Zien Mechanical Contractors No. 1, SOLAR/1057-78/10, Department of Energy, Washington D C., (October 1978).
- 7.# Monthly Performance Report, Zien Mechanical Contractors No. 1, SOLAR/1057-78/11, Department of Energy, Washington D.C., (November 1978).

#Copies of these reports may be obtained from Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

7. BIBLIOGRAPHY

1. Monthly Performance Report, Zien Mechanical Contractors No. 1,
SOLAR/1057-78/05, Department of Energy, Washington D.C.,
(May 1978).
2. Monthly Performance Report, Zien Mechanical Contractors No. 1,
SOLAR/1057-78/06, Department of Energy, Washington D.C.,
(June 1978).
3. Monthly Performance Report, Zien Mechanical Contractors No. 1,
SOLAR/1057-78/07, Department of Energy, Washington D.C.,
(July 1978).
4. Monthly Performance Report, Zien Mechanical Contractors No. 1,
SOLAR/1057-78/08, Department of Energy, Washington D.C.,
(August 1978).
5. Monthly Performance Report, Zien Mechanical Contractors No. 1,
SOLAR/1057-78/09, Department of Energy, Washington D.C.,
(September 1978).

APPENDIX A

DEFINITIONS OF PERFORMANCE FACTORS AND SOLAR TERMS

COLLECTOR ARRAY PERFORMANCE

The collector array performance is characterized by the amount of solar energy collected with respect to the energy available to be collected.

- o INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.
- o OPERATIONAL INCIDENT ENERGY (SEOP) is the amount of solar energy incident on the collector array during the time that the collector loop is active (attempting to collect energy).
- o COLLECTED SOLAR ENERGY (SECA) is the thermal energy removed from the collector array by the energy transport medium.
- o COLLECTOR ARRAY EFFICIENCY (CAREF) is the ratio of the energy collected to the total solar energy incident on the collector array. It should be emphasized that this efficiency factor is for the collector array, and available energy includes the energy incident on the array when the collector loop is inactive. This efficiency must not be confused with the more common collector efficiency figures which are determined from instantaneous test data obtained during steady-state operation of a single collector unit. These efficiency figures are often provided by collector manufacturers or presented in technical journals to characterize the functional capability of a particular collector design. In general, the collector panel maximum efficiency factor will be significantly higher than the collector array efficiency reported here.

STORAGE PERFORMANCE

The storage performance is characterized by the relationships among the energy delivered to storage, removed from storage, and the subsequent change in the amount of stored energy.

- o ENERGY TO STORAGE (STEI) is the amount of energy, both solar and auxiliary, delivered to the primary storage medium.
- o ENERGY FROM STORAGE (STEO) is the amount of energy extracted by the load subsystems from the primary storage medium.

- o CHANGE IN STORED ENERGY (STECH) is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value).
- o STORAGE AVERAGE TEMPERATURE (TST) is the mass-weighted average temperature of the primary storage medium.
- o STORAGE EFFICIENCY (STEFF) is the ratio of the sum of the energy removed from storage and the change in stored energy to the energy delivered to storage.

ENERGY COLLECTION AND STORAGE SUBSYSTEM

The Energy Collection and Storage Subsystem (ECSS) is composed of the collector array, the primary storage medium, the transport loops between these, and other components in the system design which are necessary to mechanize the collector and storage equipment.

- o INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.
- o AMBIENT TEMPERATURE (TA) is the average temperature of the outdoor environment at the site.
- o ENERGY TO LOADS (SEL) is the total thermal energy transported from the ECSS to all load subsystems.
- o AUXILIARY THERMAL ENERGY TO ECSS (CSAUX) is the total auxiliary energy supplied to the ECSS, including auxiliary energy added to the storage tank, heating devices on the collectors for freeze-protection, etc.
- o ECSS OPERATING ENERGY (CSOPE) is the critical operating energy required to support the ECSS heat transfer loops.

HOT WATER SUBSYSTEM

The hot water subsystem is characterized by a complete accounting of the energy flow into and from the subsystem, as well as an accounting of internal energy. The energy into the subsystem is composed of auxiliary fossil fuel, and electrical auxiliary thermal energy, and the operating energy for the subsystem.

- o HOT WATER LOAD (HWL) is the amount of energy required to heat the amount of hot water demanded at the site from the incoming temperature to the desired outlet temperature.

- o SOLAR FRACTION OF LOAD (HWSFR) is the percentage of the load demand which is supported by solar energy.
- o SOLAR ENERGY USED (HWSE) is the amount of solar energy supplied to the hot water subsystem.
- o OPERATING ENERGY (HWOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the subsystem.
- o AUXILIARY THERMAL USED (HWAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid, or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.
- o AUXILIARY FOSSIL FUEL (HWAFF) is the amount of fossil fuel energy supplied directly to the subsystem.
- o ELECTRICAL ENERGY SAVINGS (HWSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.
- o FOSSIL FUEL SAVINGS (HWSVF) is the estimated difference between the fossil fuel energy requirements of the alternative conventional system (carrying the full load) and the actual fossil fuel energy requirements of the subsystem.

SPACE HEATING SUBSYSTEM

The space heating subsystem is characterized by performance factors accounting for the complete energy flow into the subsystem. The average building temperature is tabulated to indicate the relative performance of the subsystem in satisfying the space heating load and in controlling the temperature of the conditioned space.

- o SPACE HEATING LOAD (HL) is the sensible energy added to the air in the building.
- o SOLAR FRACTION OF LOAD (HSFR) is the fraction of the sensible energy added to the air in the building derived from the solar energy system.
- o SOLAR ENERGY USED (HSE) is the amount of solar energy supplied to the space heating subsystem.

- o OPERATING ENERGY (HOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the system.
- o AUXILIARY THERMAL USED (HAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.
- o AUXILIARY ELECTRICAL FUEL (HAE) is the amount of electrical energy supplied directly to the subsystem.
- o ELECTRICAL ENERGY SAVINGS (HSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.
- o BUILDING TEMPERATURE (TB) is the average heated space dry bulb temperature.

APPENDIX B
SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS
ZIEN MECHANICAL CONTRACTORS NO. 1

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance calculations on the system and its major subsystems. These calculations are based on physical measurement data taken from each sensor every 320 seconds. This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This appendix describes the general computational methods and the specific energy balance equations used for this site.

Data samples from the system measurements are integrated to provide discrete approximations of the continuous functions which characterize the system's dynamic behavior. This integration is performed by summation of the product of the measured rate of the appropriate performance parameters and the sampling interval over the total time period of interest.

There are several general forms of integration equations which are applied to each site. These general forms are exemplified as follows: The total solar energy available to the collector array is given by

$$\text{SOLAR ENERGY AVAILABLE} = (1/60) \sum [I001 \times \text{AREA}] \times \Delta\tau$$

where I001 is the solar radiation measurement provided by the pyranometer in Btu per square foot per hour, AREA is the area of the collector array in square feet, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

$$\text{COLLECTED SOLAR ENERGY} = \sum [M100 \times \Delta H] \times \Delta\tau$$

where M100 is the mass flow rate of the heat transfer fluid in lb_m/min and ΔH is the enthalpy change, in Btu/lb_m, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

$$\Delta H = \bar{C}_p \Delta T$$

where \bar{C}_p is the average specific heat, in Btu/(lb_m-°F), of the heat transfer fluid and ΔT , in °F, is the temperature differential across the heat exchanging component.

For an air system ΔH is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in Btu/lb_m, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

$$\text{ECSS OPERATING ENERGY} = (3413/60) \sum [EP100] \times \Delta \tau$$

where EP100 is the power required by electrical equipment in kilowatts and the two factors (1/60) and 3413 correct the data to Btu/min.

These equations are comparable to those specified in "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program." This document was prepared by an interagency committee of the Government, and presents guidelines for thermal performance evaluation.

Performance factors are computed for each hour of the day. Each integration process, therefore, is performed over a period of one hour. Since long-term performance data is desired, it is necessary to build these hourly performance factors to daily values. This is accomplished, for energy parameters, by summing the 24 hourly values. For temperatures, the hourly values are averaged. Certain special factors, such as efficiencies, require appropriate handling to properly weight each hourly sample for the daily value computation. Similar procedures are required to convert daily values to monthly values.

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

NOTE: SENSOR IDENTIFICATION (MEASUREMENT) NUMBERS REFERENCE SYSTEM SCHEMATIC FIGURE 3-1

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma T001 \times \Delta\tau$$

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma [(T600)] \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \Sigma T001 \times \Delta\tau$$

FOR \pm 3 HOURS FROM SOLAR NOON

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT²)

$$SE = (1/60) \times \Sigma I001 \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \Sigma [I001 \times CLAREA] \times \Delta\tau$$

WHEN THE COLLECTOR LOOP IS ACTIVE

HUMIDITY RATIO FUNCTION (BTU/lb_m-°F)

$$HRF = (0.24 + 0.444 \times HR)$$

WHERE 0.24 IS THE SPECIFIC HEAT AND HR IS THE HUMIDITY RATIO

OF THE TRANSPORT AIR. THIS FUNCTION IS USED WHENEVER THE

HUMIDITY RATIO WILL REMAIN CONSTANT AS THE TRANSPORT AIR FLOWS

THROUGH A HEAT EXCHANGING DEVICE

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma (1/60) [M100 \times HRF \times (T150 - T100)] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma M100 * HRF (T150 - T100)$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma [(M400 * HRF * (T452 - T402))] - [COMPEFF * EPCONST * EP400]$$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = (1/60) \times \Sigma (T204 + T206) \times \Delta\tau$$

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

$$CSEO = STEO$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = EPCONST * \Sigma EP200 * \Delta\tau$$

WHEN SYSTEM IS IN THE COLLECTOR-TO-STORAGE MODE

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = EPCONST * \Sigma EP401 \Delta\tau$$

WHEN SYSTEM IS IN THE STORAGE-TO-SPACE HEATING MODE

SPACE HEATING SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$$HAE = EPCONST * EP402 + COMEFF * EPCONST * EP400$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = HAE$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = M400 * HRF * (T452 - T40) + EPCONST * EP402$$

BUILDING TEMPERATURE (°F)

$$TOFF = (1/60) \times \Sigma T600 \times \Delta\tau$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

$$CAREF = SECA/SEA$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = STOCAP1 * (1 - VOID) * RHOR * CPR * (TANKT - TANKT_p)$$

WHERE THE SUBSCRIPT _p REFERS TO A PRIOR REFERENCE VALUE

STORAGE EFFICIENCY

$$STEFF = (STECH + STEO)/STEI$$

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

$$SEL = CSEO$$

ECSS SOLAR CONVERSION EFFICIENCY

$$CSCEF = CSEO/SEA$$

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

$$HSFR = 100 \times HSE1/HL$$

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HSVE = HSE/(HPCOP(TA)) * HPFRAC * (1 - HPFRAC) - HOPE1$$

SYSTEM LOAD (BTU)

$$HL = HPHL + HAE1$$

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

$$SFR = HSFR$$

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

$$HAT = HAE$$

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

$$HAE = HAE1 + COMEFF * HAE2$$

SYSTEM OPERATING ENERGY (BTU)

$$SYSOPE = HOPE + CSOPE$$

TOTAL ENERGY CONSUMED (BTU)

$$TECSM = SYSOPE + HAE + SECA$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

$$HSVE = HSE / (HPCOP (TA)) * HPFRAC * (1 - HPFRAC) - HOPE1$$

SYSTEM PERFORMANCE FACTOR

$$SYSPF = SYSL / ((AXE + SYSOPE) \times 3.33)$$

APPENDIX C

LONG-TERM AVERAGE WEATHER CONDITIONS

This appendix contains a table which lists the long-term average weather conditions for each month of the year for this site.

SITE: ZIEN MECH. 184. LOCATION: MILWAUKEE WI
 ANALYST: C. WERNER PDRIVE NO.: 16.
 COLLECTOR TILT: 53.00 (DEGREES) COLLECTOR AZIMUTH: 0.0 (DEGREES)
 LATITUDE: 43.00 (DEGREES) RUN DATE: 6/07/79

MONTH	HOBAR	HBAR	KBAR	RBAR	SHAR	HDD	CDD	TBAR
JAN	1165.	479.	0.41131	1.885	904.	1414	0	19.
FEB	1640.	737.	0.44969	1.556	1148.	1190	0	23.
MAR	2270.	1088.	0.47920	1.237	1346.	1042	0	31.
APR	2945.	1442.	0.48947	0.979	1412.	639	0	45.
MAY	3437.	1770.	0.51489	0.833	1474.	348	13	54.
JUN	3643.	1976.	0.54247	0.773	1528.	90	75	65.
JUL	3536.	1961.	0.55469	0.798	1566.	15	167	70.
AUG	3132.	1718.	0.54851	0.917	1575.	36	166	69.
SEP	2511.	1309.	0.52127	1.137	1489.	140	23	61.
OCT	1822.	907.	0.49769	1.475	1338.	440	6	51.
NOV	1275.	524.	0.41059	1.771	927.	855	0	37.
DEC	1038.	380.	0.36574	1.911	726.	1205	0	24.

LEGEND:

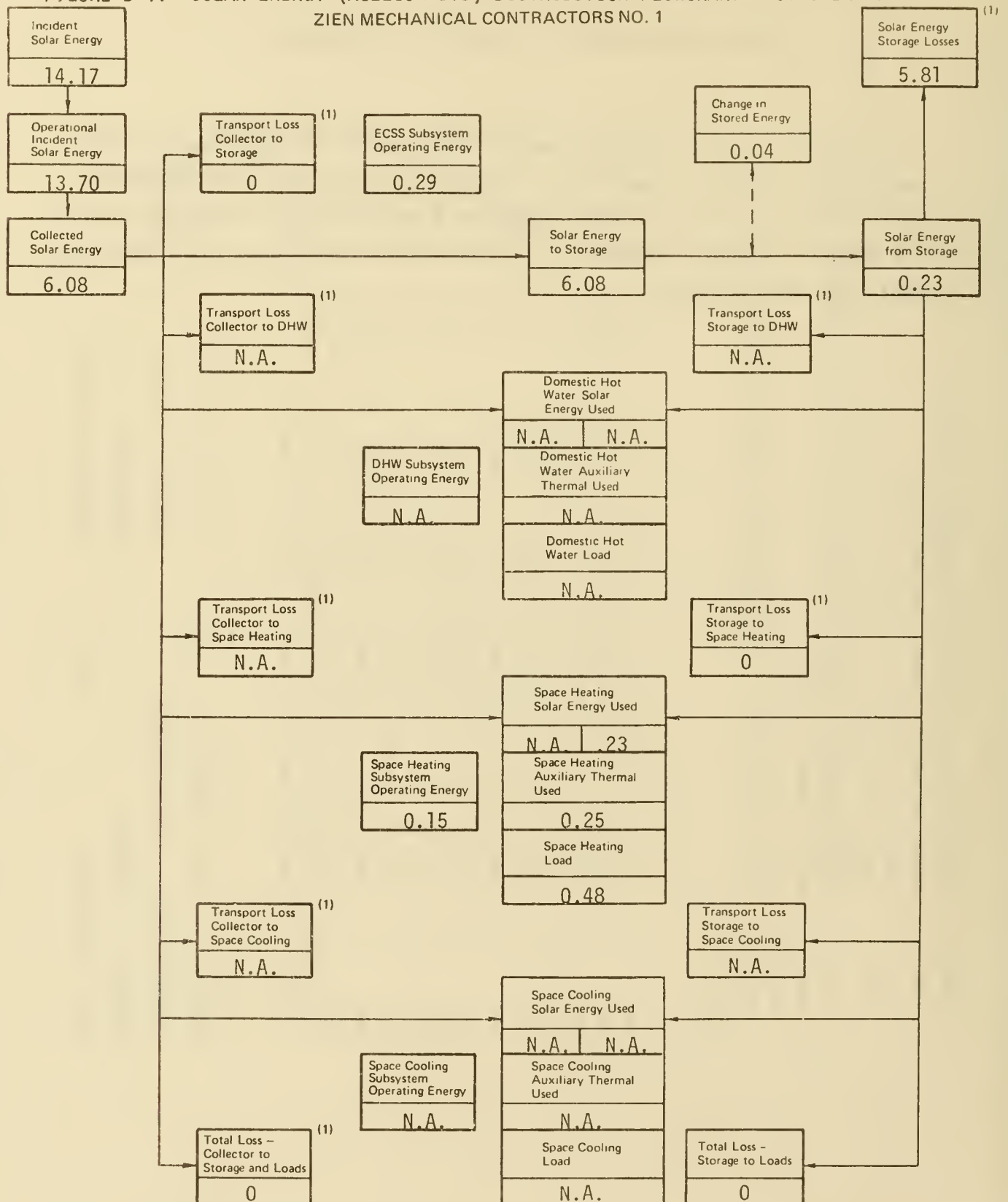
HOBAR ==> MONTHLY AVERAGE DAILY EXTRATERRESTRIAL RADIATION (IDEAL) IN BTU/DAY-FT2.
 HBAR ==> MONTHLY AVERAGE DAILY RADIATION (ACTUAL) IN BTU/DAY-FT2.
 KBAR ==> RATIO OF HBAR TO HOBAR.
 RBAR ==> RATIO OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACE TO THAT ON A HORIZONTAL SURFACE FOR EACH MONTH (I.E., MULTIPLIER OBTAINED BY TILTING).
 SBAR ==> MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE (I.E., RBAR * HBAR) IN BTU/DAY-FT2.
 HDD ==> NUMBER OF HEATING DEGREE DAYS PER MONTH.
 CDD ==> NUMBER OF COOLING DEGREE DAYS PER MONTH.
 TBAR ==> AVERAGE AMBIENT TEMPERATURE IN DEGREES FAHRENHEIT.

APPENDIX D

MONTHLY SOLAR ENERGY DISTRIBUTION FLOWCHARTS

The flowcharts in this appendix depict the quantity of solar energy corresponding to each major component or characteristic of the Zien Mechanical Contractors No. 1 solar energy system for 6 months of the reporting period. Each monthly flowchart represents a solar energy balance as the total input equals the total output.

FIGURE D-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - OCTOBER 1978
ZIEN MECHANICAL CONTRACTORS NO. 1



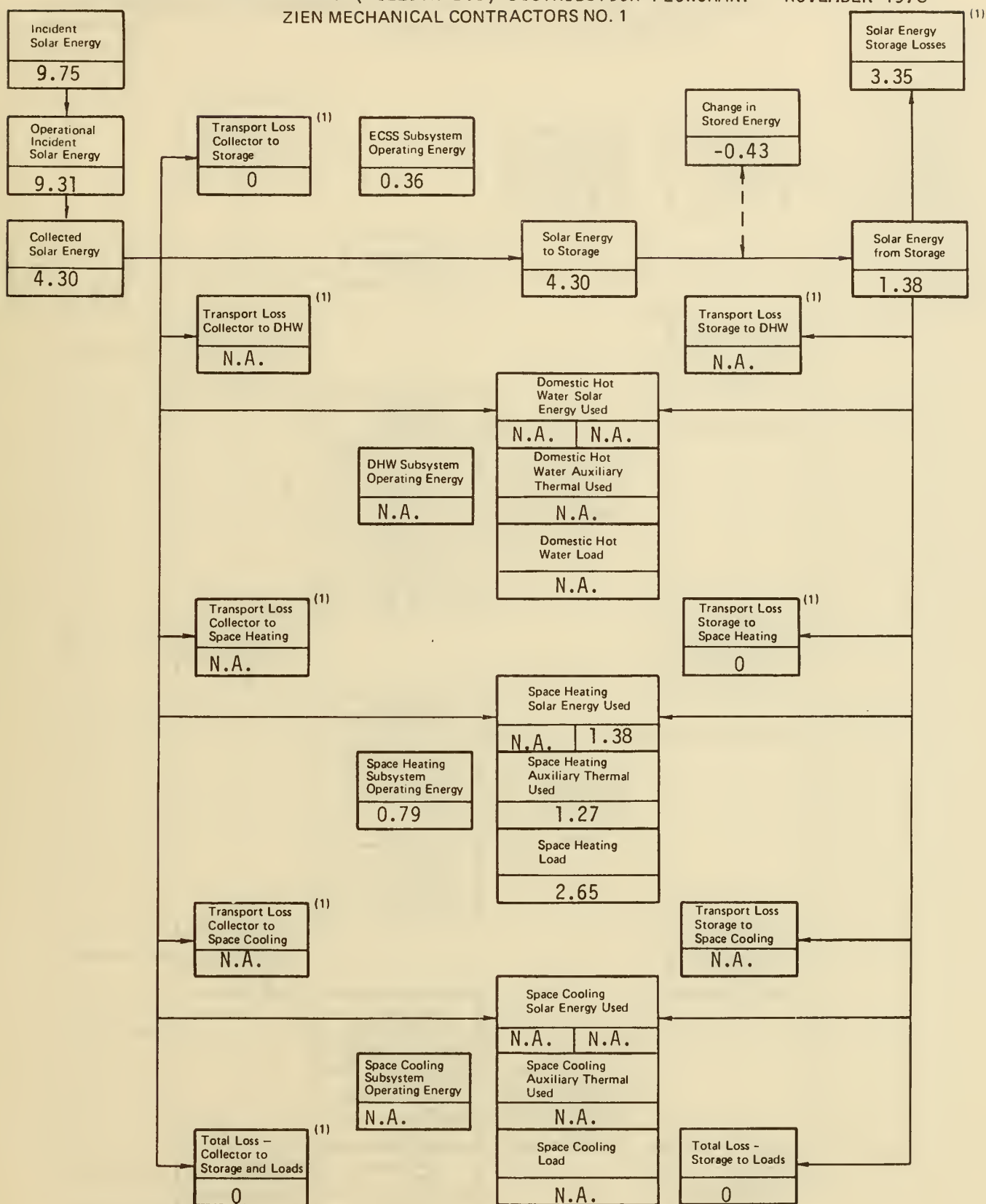
* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known - see text for discussion)

S002

FIGURE D-2. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - NOVEMBER 1978
ZIEN MECHANICAL CONTRACTORS NO. 1



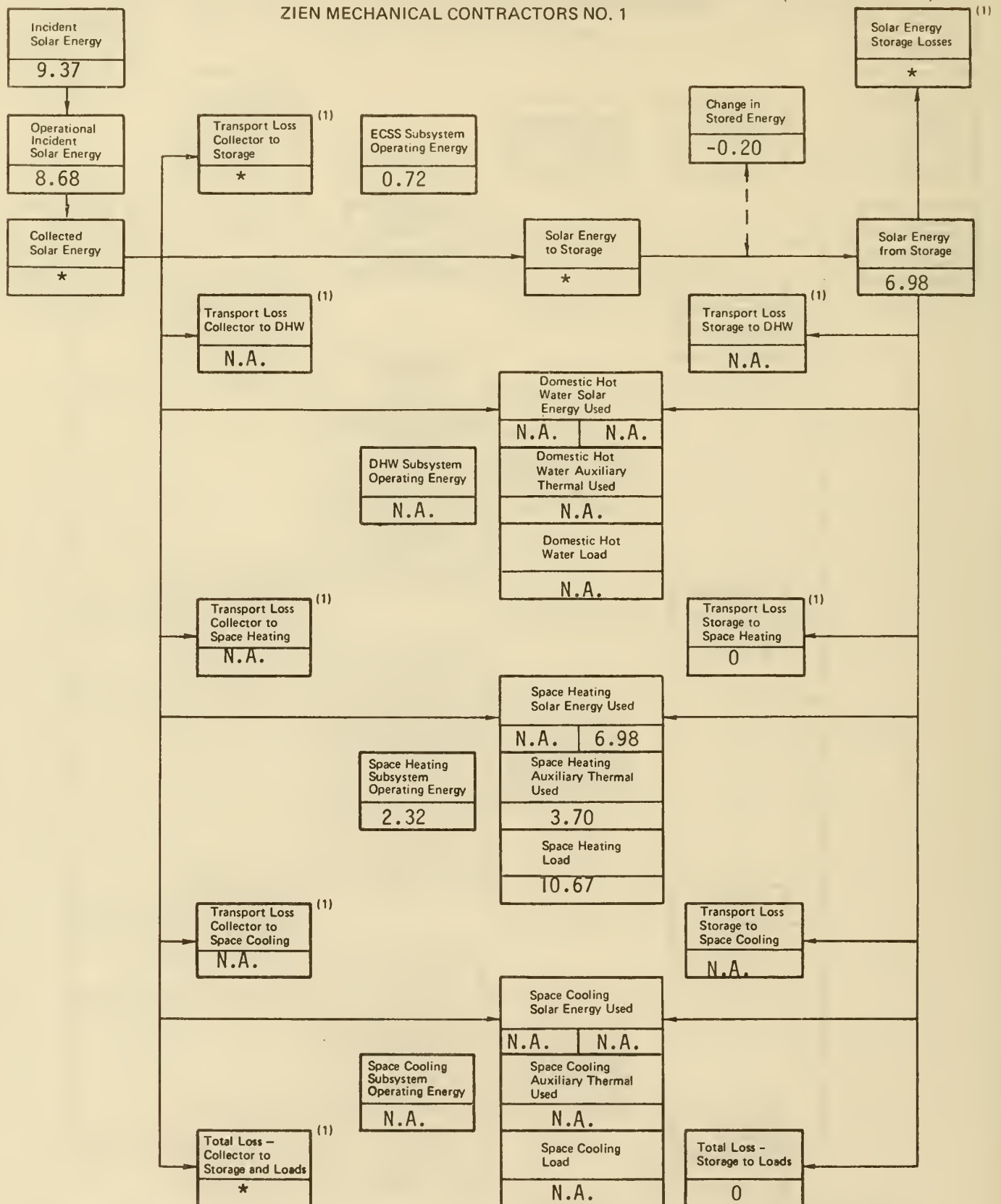
* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known - see text for discussion)

5002

FIGURE D-3. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - (DECEMBER 1978)
ZIEN MECHANICAL CONTRACTORS NO. 1



ZIEN MECHANICAL CONTRACTORS NO. 1

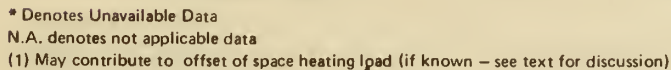
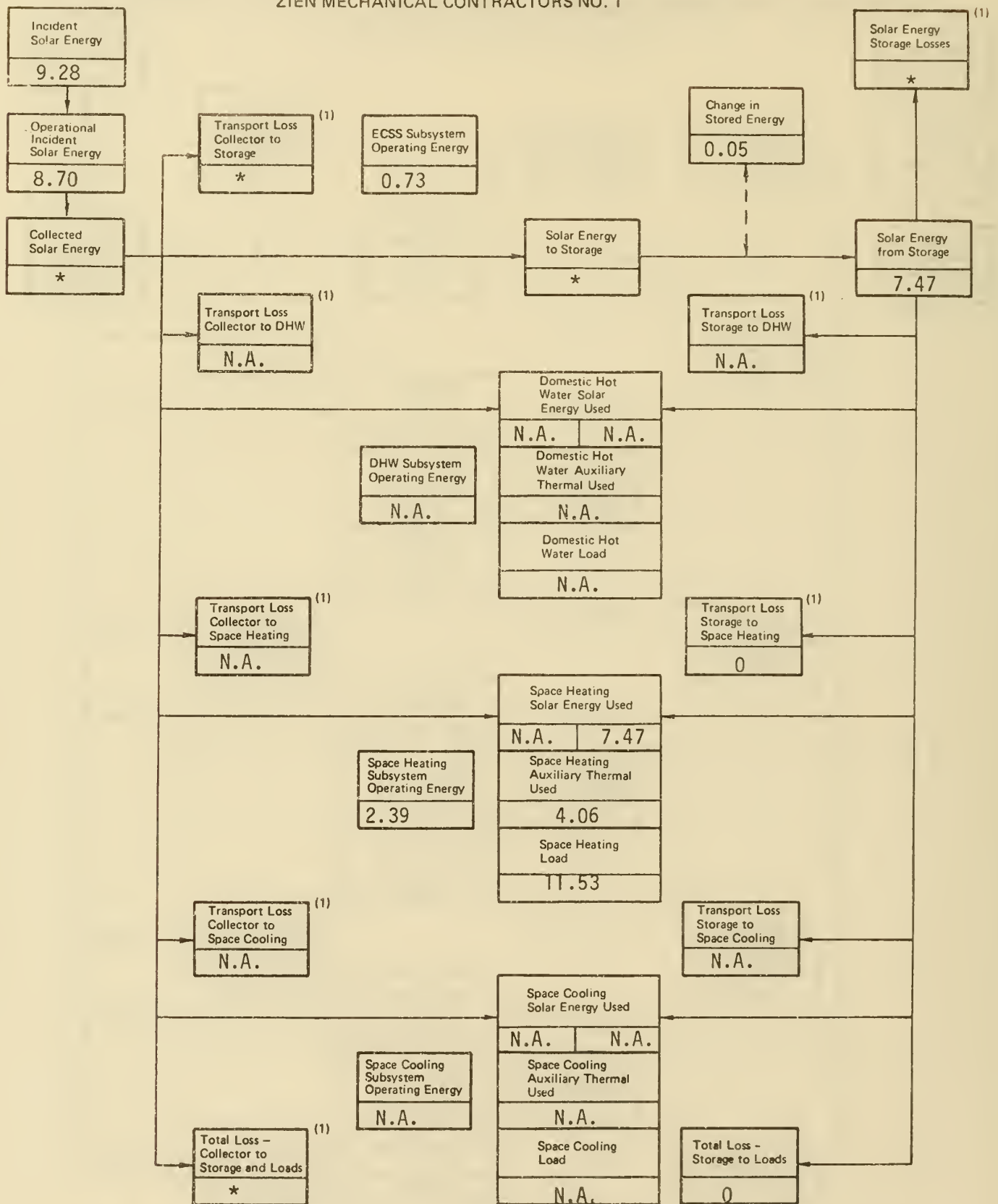


FIGURE D-5. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - (FEBRUARY 1979)
ZIEN MECHANICAL CONTRACTORS NO. 1



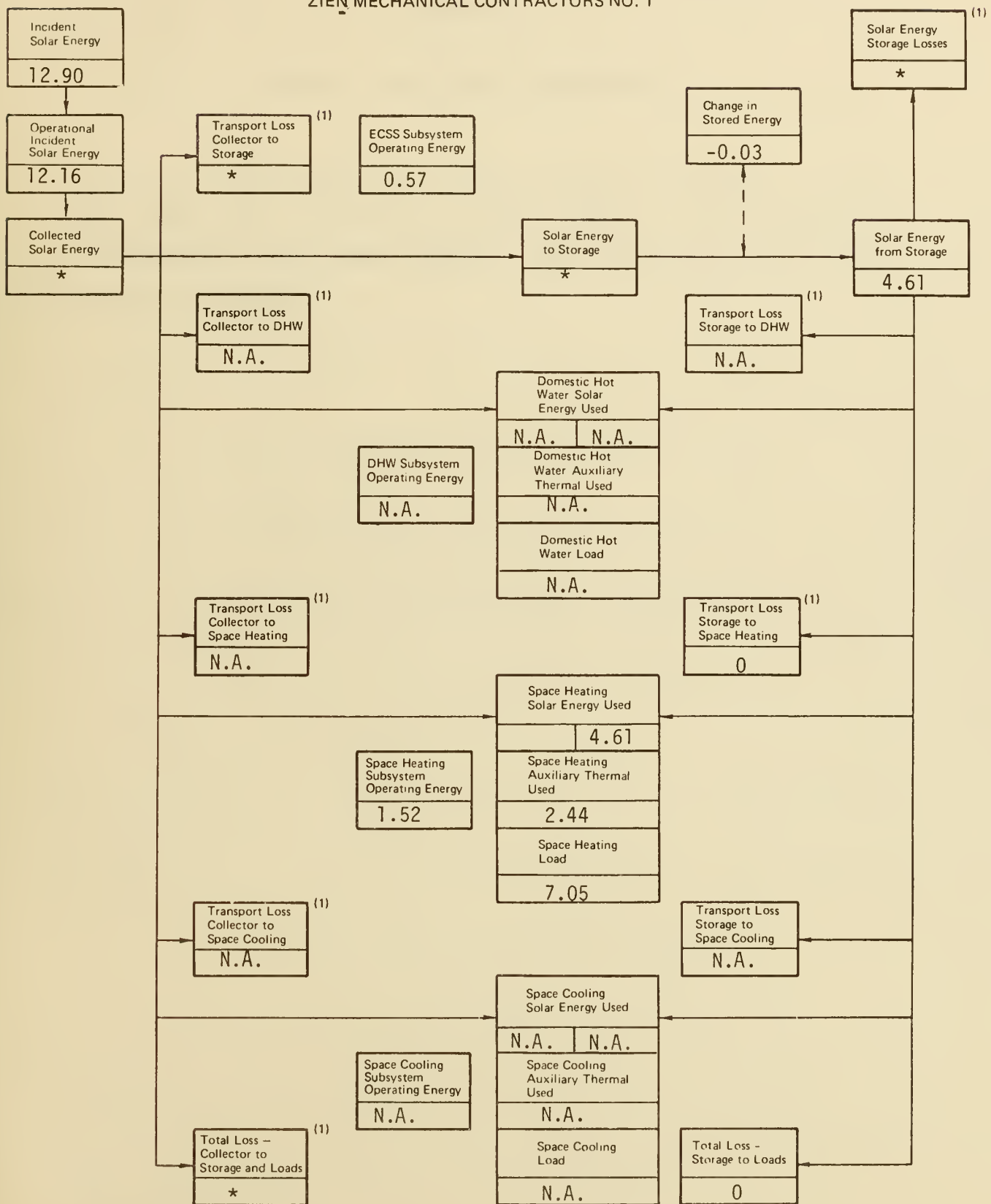
* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known - see text for discussion)

9002

FIGURE D-6. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - (MARCH 1979)
ZIEN MECHANICAL CONTRACTORS NO. 1



* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known - see text for discussion)

S002

APPENDIX E

MONTHLY SOLAR ENERGY DISTRIBUTIONS

The data tables provided in this appendix present an indication of solar energy distribution, intentional and unintentional, in the Zien Mechanical Contractors No. 1 solar energy system. Tables are provided for 6 months of the reporting period.

TABLE E-1. SOLAR ENERGY DISTRIBUTION - OCTOBER 1978
 ZIEN MECHANICAL CONTRACTORS NO. 1

<u>6.08</u> 100%	million Btu	TOTAL SOLAR ENERGY COLLECTED
<u>0.23</u> 4 %	million Btu	SOLAR ENERGY TO LOADS
<u>N.A.</u> %	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
<u>0.23</u> %	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
<u>N.A.</u> %	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
<u>5.81</u> 96 %	million Btu	SOLAR ENERGY LOSSES
<u>5.81</u> 96 %	million Btu	SOLAR ENERGY LOSS FROM STORAGE
<u>0</u> 0 %	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
<u>0</u> 0 %	million Btu	COLLECTOR TO STORAGE LOSS
<u>N.A.</u> %	million Btu	COLLECTOR TO LOAD LOSS
<u>N.A.</u> %	million Btu	COLLECTOR TO DHW LOSS
<u>N.A.</u> %	million Btu	COLLECTOR TO SPACE HEATING LOSS
<u>N.A.</u> %	million Btu	COLLECTOR TO SPACE COOLING LOSS
<u>5.81</u> 96 %	million Btu	STORAGE TO LOAD LOSS
<u>N.A.</u> %	million Btu	STORAGE TO DHW LOSS
<u>5.81</u> 96 %	million Btu	STORAGE TO SPACE HEATING LOSS
<u>N.A.</u> %	million Btu	STORAGE TO SPACE COOLING LOSS
<u>0.042</u> 0 %	million Btu	SOLAR ENERGY STORAGE CHANGE

N.A. - Denotes not applicable data

TABLE E-2. SOLAR ENERGY DISTRIBUTION - NOVEMBER 1978
 ZIEN MECHANICAL CONTRACTORS NO. 1

<u>4.30</u> 100%	million Btu	TOTAL SOLAR ENERGY COLLECTED
<u>1.38</u> 32 %	million Btu	SOLAR ENERGY TO LOADS
<u>N.A.</u> %	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
<u>1.38</u> 32 %	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
<u>N.A.</u> %	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
<u>3.35</u> 78 %	million Btu	SOLAR ENERGY LOSSES
<u>3.35</u> 78 %	million Btu	SOLAR ENERGY LOSS FROM STORAGE
<u>0</u> 0 %	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
<u>N.A.</u> %	million Btu	COLLECTOR TO STORAGE LOSS
<u>3.35</u> 78%	million Btu	COLLECTOR TO LOAD LOSS
<u>N.A.</u> %	million Btu	COLLECTOR TO DHW LOSS
<u>2.49</u> 58 %	million Btu	COLLECTOR TO SPACE HEATING LOSS
<u>N.A.</u> %	million Btu	COLLECTOR TO SPACE COOLING LOSS
<u>3.35</u> 58%	million Btu	STORAGE TO LOAD LOSS
<u>N.A.</u> %	million Btu	STORAGE TO DHW LOSS
<u>2.49</u> 58 %	million Btu	STORAGE TO SPACE HEATING LOSS
<u>N.A.</u> %	million Btu	STORAGE TO SPACE COOLING LOSS
<u>-0.43</u> -10%	million Btu	SOLAR ENERGY STORAGE CHANGE

TABLE E-3. SOLAR ENERGY DISTRIBUTION SUMMARY - (DECEMBER 1978)
 ZIEN MECHANICAL CONTRACTORS NO. 1

$\frac{*}{100\%}$	million Btu	TOTAL SOLAR ENERGY COLLECTED
$\frac{6.98}{* \%}$	million Btu	SOLAR ENERGY TO LOADS
$\frac{N.A.}{\%}$	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
$\frac{6.98}{* \%}$	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
$\frac{N.A.}{\%}$	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSSES
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSS FROM STORAGE
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO STORAGE LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO LOAD LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO DHW LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO SPACE HEATING LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO SPACE COOLING LOSS
$\frac{*}{* \%}$	million Btu	STORAGE TO LOAD LOSS
$\frac{N.A.}{\%}$	million Btu	STORAGE TO DHW LOSS
$\frac{*}{* \%}$	million Btu	STORAGE TO SPACE HEATING LOSS
$\frac{N.A.}{\%}$	million Btu	STORAGE TO SPACE COOLING LOSS
$\frac{-0.2}{* \%}$	million Btu	SOLAR ENERGY STORAGE CHANGE

* - Denotes Unavailable Data

N.A. - Denotes not applicable data

TABLE E-4. SOLAR ENERGY DISTRIBUTION - (JANUARY 1979)
 ZIEN MECHANICAL CONTRACTORS NO. 1

$\frac{*}{100\%}$	million Btu	TOTAL SOLAR ENERGY COLLECTED
$\frac{8.75}{* \%}$	million Btu	SOLAR ENERGY TO LOADS
$\frac{N.A.}{\%}$	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
$\frac{8.75}{\%}$	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
$\frac{N.A.}{\%}$	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSSES
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSS FROM STORAGE
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO STORAGE LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO LOAD LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO DHW LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO SPACE HEATING LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO SPACE COOLING LOSS
$\frac{*}{* \%}$	million Btu	STORAGE TO LOAD LOSS
$\frac{N.A.}{\%}$	million Btu	STORAGE TO DHW LOSS
$\frac{*}{* \%}$	million Btu	STORAGE TO SPACE HEATING LOSS
$\frac{N.A.}{\%}$	million Btu	STORAGE TO SPACE COOLING LOSS
$\frac{0.12}{* \%}$	million Btu	SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data E-5

N.A. - Denotes not applicable data

TABLE E-5. SOLAR ENERGY DISTRIBUTION - (FEBRUARY 1979)
 ZIEN MECHANICAL CONTRACTORS NO. 1

$\frac{*}{100\%}$	million Btu	TOTAL SOLAR ENERGY COLLECTED
$\frac{7.47}{* \%}$	million Btu	SOLAR ENERGY TO LOADS
$\frac{N.A.}{\%}$	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
$\frac{7.47}{* \%}$	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
$\frac{N.A.}{\%}$	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSSES
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSS FROM STORAGE
$\frac{*}{* \%}$	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
$\frac{*}{* \%}$	million Btu	COLLECTOR TO STORAGE LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO LOAD LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO DHW LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO SPACE HEATING LOSS
$\frac{N.A.}{\%}$	million Btu	COLLECTOR TO SPACE COOLING LOSS
$\frac{*}{* \%}$	million Btu	STORAGE TO LOAD LOSS
$\frac{N.A.}{\%}$	million Btu	STORAGE TO DHW LOSS
$\frac{*}{* \%}$	million Btu	STORAGE TO SPACE HEATING LOSS
$\frac{N.A.}{\%}$	million Btu	STORAGE TO SPACE COOLING LOSS
$\frac{0.05}{* \%}$	million Btu	SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data E-6

N.A. - Denotes not applicable data

TABLE E-6. SOLAR ENERGY DISTRIBUTION - (MARCH 1979)
 ZIEN MECHANICAL CONTRACTORS NO. 1

<u>* 100%</u>	million Btu	TOTAL SOLAR ENERGY COLLECTED
<u>4.61 * %</u>	million Btu	SOLAR ENERGY TO LOADS
<u>N.A. %</u>	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
<u>4.61 * %</u>	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
<u>N.A. %</u>	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
<u>* * %</u>	million Btu	SOLAR ENERGY LOSSES
<u>* * %</u>	million Btu	SOLAR ENERGY LOSS FROM STORAGE
<u>* * %</u>	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
<u>* * %</u>	million Btu	COLLECTOR TO STORAGE LOSS
<u>N.A. %</u>	million Btu	COLLECTOR TO LOAD LOSS
<u>N.A. %</u>	million Btu	COLLECTOR TO DHW LOSS
<u>* * %</u>	million Btu	COLLECTOR TO SPACE HEATING LOSS
<u>N.A. %</u>	million Btu	COLLECTOR TO SPACE COOLING LOSS
<u>* * %</u>	million Btu	STORAGE TO LOAD LOSS
<u>N.A. %</u>	million Btu	STORAGE TO DHW LOSS
<u>* * %</u>	million Btu	STORAGE TO SPACE HEATING LOSS
<u>N.A. %</u>	million Btu	STORAGE TO SPACE COOLING LOSS
<u>-0.03 * %</u>	million Btu	SOLAR ENERGY STORAGE CHANGE

* - Denotes unavailable data E-7

N.A. - Denotes not applicable data

UNIVERSITY OF FLORIDA



3 1262 05391 1862

